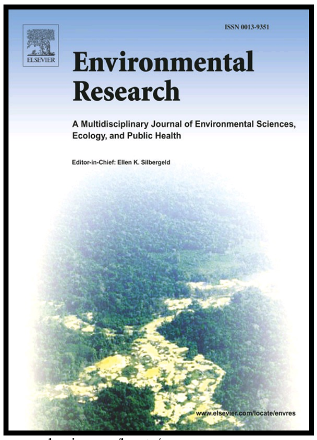
Author's Accepted Manuscript



www.elsevier.com/locate/envres

Geospatial Analyses of Adverse Birth Outcomes In Southwestern Ontario: Examining The Impact of Environmental Factors

Jamie A. Seabrook, Alexandra Smith, Andrew F. Clark, Jason A. Gilliland

PII: S0013-9351(18)30703-5
DOI: https://doi.org/10.1016/j.envres.2018.12.068
Reference: YENRS8249

To appear in: *Environmental Research*

Received date: 1 September 2018
Revised date: 1 December 2018
Accepted date: 30 December 2018

Cite this article as: Jamie A. Seabrook, Alexandra Smith, Andrew F. Clark and Jason A. Gilliland, Geospatial Analyses of Adverse Birth Outcomes In Southwestern Ontario: Examining The Impact of Environmental Factors, *Environmental Research,* https://doi.org/10.1016/j.envres.2018.12.068

GEOSPATIAL ANALYSES OF ADVERSE BIRTH OUTCOMES IN SOUTHWESTERN ONTARIO: EXAMINING THE IMPACT OF ENVIRONMENTAL FACTORS

Jamie A. Seabrook, PhD[1,6], Alexandra Smith, MScFN (c)[1], Andrew F. Clark, PhD[4,6,7], Jason A. Gilliland, PhD[2-8]

[1]School of Food and Nutritional Sciences, Brescia University College, 1285 Western Road, London, Ontario, Canada, N6G 1H2

[2]Department of Paediatrics, 800 Commissioners Road East, Western University, London, Ontario, Canada, N6A 5W9

[3]Department of Epidemiology and Biostatistics,1151 Richmond Street, Western University, London, Ontario, Canada, N6A 5C1

[4]Children's Health Research Institute, 800 Commissioners Road East, London, Ontario, Canada, N6C 2V5

[5]Lawson Health Research Institute, 750 Base Line Road East, London, Ontario, Canada, N6C 2R5

[6]Human Environments Analysis Laboratory, 1151 Richmond Street, Western University, London, Ontario, Canada, N6A 3K7

[7]Department of Geography, 1151 Richmond Street, Western University, London, Ontario, Canada, N6A 5C2

[8]School of Health Studies, 1151 Richmond Street, Western University, London, Ontario, Canada, N6A 3K7

***Corresponding Author:** Dr. Jason A. Gilliland Human Environments Analysis Laboratory (HEAL) Geography, Paediatrics, Epidemiology & Biostatistics, and School of Health Studies University of Western Ontario, 1151 Richmond St, London, Ontario, Canada N6A 3K7 Tel: (519) 661-2111 ext. 81239; Fax: (519) 661-3750 , jgillila@uwo.ca

ABSTRACT

Background:

A growing body of research has examined the association between exposure to environmental factors during pregnancy and adverse birth outcomes; however, many studies do not control for potential covariates and findings vary considerably.

Objective:

To test the relative influence of environmental factors including exposure to air pollution, major roads, highways, industry, parks, greenspaces, and food retailers on low birth weight (LBW) and preterm birth (PTB) in Southwestern Ontario (SWO), Canada, while accounting for medical (e.g., previous preterm birth, gestational diabetes), behavioral (e.g., alcohol, smoking), demographic (e.g., maternal age, body mass index), and neighborhood-level socioeconomic (e.g., household income, education) factors.

Methods:

This retrospective cohort study consisted of a large sample of pregnant women from SWO who gave birth to singleton newborns between February 2009 and February 2014 at London Health Sciences Centre. Data on maternal postal codes were entered into a Geographic Information System to map the distribution of maternal residences and determine selected characteristics of their neighborhood environments (i.e., socioeconomic, built, natural). These variables were developed based on postal codes where the mothers lived prior to giving birth. Logistic regression was used to assess the relative effects of the physical environment, socioeconomic status, clinical history, and behavioral risk factors on mothers having a LBW or PTB infant.

Results:

Out of 25,263 live births, 5.7% were LBW and 7.5% were PTB. Exposure to sulfur dioxide was a top predictor of both LBW and PTB. For every one-unit increase in sulfur dioxide, the odds of a LBW and PTB were 3.4

(95% CI: 2.2, 5.2) and 2.0 (95% CI: 1.4, 3.0) times higher, after controlling for other variables in the model, respectively ($p<0.001$). Previous PTB was also highly associated with both birth outcomes.

Conclusions:

Health care providers should be informed about the hazards of air pollution to developing fetuses so that recommendations can be made to their pregnant patients about limiting exposure when air quality is poor.

Keywords: Premature birth, infant, low birth weight, sulfur dioxide, air pollution

1. Introduction

Adverse birth outcomes, such as low birth weight (LBW) and preterm birth (PTB), are associated with a higher risk of infant morbidity and mortality, as well as hypertension, type 2 diabetes, and cardiovascular disease in adulthood (Barker 2004; Campbell et al. 2018; Nowack and Giurgescu 2017; Ncube et al. 2016; Seabrook et al. 2018; Van Lieshout et al. 2015; Woods et al. 2017). Approximately 7% of babies are born LBW (<2500 g) in developed countries, compared to 16.5% in developing countries (Lamichhane et al. 2015); PTB (<37 weeks gestational age) ranges from 5% to 18% across 184 countries, with higher rates occurring in lower-income countries (WHO 2018).

While the etiology of LBW and PTB is multifactorial and not well understood, a growing body of research in environmental epidemiology has examined the impact of maternal exposure to air pollution during pregnancy. Conclusions drawn from this research have varied considerably, with some systematic reviews suggesting causal relationships (Lacasana et al. 2005), and others suggesting no effects (Glinianaia et al. 2004). For example, Glinianaia et al. (2004) found little consistency in the association between particulate air pollution on birth weight, gestational age at delivery, and stillbirth (n=12 studies). Maisonet et al. (2004) discovered a weak but statistically significant association between air pollution and PTB (n=4 studies) and intrauterine growth restriction (IUGR; n=6 studies), but not LBW (n=4 studies). Lacasana et al. (2005) showed that an increase in 10 μg/m3 of particle concentration (measured as PM10) was associated with a 5% increase in post-neonatal mortality for all causes and a 22% increase for post-neonatal mortality for respiratory diseases. Sram et al. (2005) suggest a causal relationship between air pollution and LBW (n=9 studies), but not for PTB (n=4 studies) or IUGR (n=4 studies). However, inferring causality based on nine studies is problematic, especially when no specific pollutant had a significant impact on LBW. Finally, in a systematic review examining the interactive effects between gender and air pollution on birth outcomes, the risk of LBW was higher in males in the presence of high levels of air pollution (n=4 studies), although the evidence was limited and inconclusive since "a proper test of interaction could not be undertaken" (Ghosh et al. 2007). A key limitation of these reviews, however, was that none of them assessed the impact of individual pollutants on adverse birth outcomes.

Given the persistent association between socioeconomic status (SES) and health disparities (Phelan et al. 2010; Seabrook and Avison 2012), it has been suggested that studies linking the physical environment and birth outcomes must include indices of SES, to control for confounding, and to examine interactions between factors (Genereux et al. 2008; Zeka et al. 2008). Despite these recommendations, most epidemiologic studies of birth outcomes continue to assess the impact of either the physical environment or SES, but rarely both (Zeka et al. 2008). It is plausible, however, that women living in socioeconomically deprived neighborhoods may be more exposed to pollution than those living in affluent neighborhoods. Evidence suggests that higher exposure to air pollution is associated with lower levels of greenness among pregnant women (Dadvand et al. 2012), and that green space reduces psychological stress and depression (Ward Thompson et al. 2012). To date, most studies have found a significant risk-reducing effect of green space (e.g., proximity to parks, tree density) on adverse birth outcomes (Woods et al. 2017).

The objective of this study was to build a hierarchical statistical model to test the relative influence of environmental (e.g., air pollution, park space), medical (e.g., previous PTB, gestational diabetes), behavioral (e.g., alcohol, smoking), demographic (e.g., maternal age, body mass index), and neighborhood SES (e.g., household income, education) factors associated with LBW and PTB in Southwestern Ontario, Canada.

2. Methods

2.1. Data Collection and Sample

This retrospective hospital-based cohort study consisted of a large sample of pregnant women from Southwestern Ontario (SWO). Data were obtained from the perinatal and neonatal databases at London Health Sciences Centre (LHSC), a tertiary care facility with a catchment area of 1.5 million patients per year. Data for all births at LHSC were prospectively entered from medical charts, and birth and neonatal records were recorded by a research assistant (Lackmann et al. 2001). Inclusion criteria were women who resided in SWO and who gave birth to singleton newborns without congenital anomalies between February 2009 and February 2014 at LHSC. Women who lived in a postal code outside of SWO were excluded from the study. Demographic data, medical history, and behavioral risk-taking factors were captured from the perinatal and neonatal databases.

2.2. *Outcome Variables*

For our primary outcome variables, LBW was defined as a birth weight <2500 g, and PTB as a live birth of <37 weeks gestational age. Neonates who are born LBW include those who are both preterm and full-term, and LBW is the most commonly reported birth outcome with respect to air pollution (Ritz and Wilhelm 2008). The final sample consisted of 25,263 live births. The study received approval from the Western University Health Science Research Ethics Board (109406) and the Lawson Health Research Institute in London, Canada.

2.3. *Predictor Variables*

Environmental variables were developed based on 6-digit postal codes where the mothers lived prior to giving birth. The postal code identified each patient’s approximate home location. Postal codes were geocoded and mapped in a Geographic Information System (ArcGIS 10.4, ESRI Redlands, CA) using a population-weighted centroid, which provides the most representative location for the postal code area (DMTI Spatial Inc, 2016). Neighborhood-level socioeconomic status variables (e.g., maternal education, median household income) are measured based on the census dissemination area (DA) that a patient's postal code falls within; DAs are the smallest geographical unit for which Statistics Canada releases the general population data required for this study. All neighborhood-level data were extracted from the 2011 National Household Survey (Statistics Canada 2011). Information on neighborhood-level SES variables, and how they were operationalized, has been reported elsewhere [blinded]. Maternal postal codes were also used to develop a series of environmental variables (built and natural), which were derived using spatial analysis in ArcGIS 10.4 for each patient using spatial data from Environment and Climate Change Canada and DMTI Spatial. A full list of variables used in this study can be found in Table 1. A description of the environmental variables, including their sources and how they were measured, is provided in Table 2.

2.4. Statistical Analysis

Data were analyzed using IBM SPSS Statistics, version 23 (Armonk, NY: IBM Corp.). The mean and standard deviation, or median and interquartile range (IQR), was used to describe continuous variables, whereas percentages were used to summarize categorical variables. Since the data were organized at more than one level (i.e., individual- and neighborhood-level), the analytic plan was to run multi-level binary logistic regression models for LBW and PTB. However, intraclass correlations (ICCs) revealed that observations in the same DA were unrelated to observations from other DAs. With ICCs close to 0, this suggests that the observations are independent of each other. Therefore, standard logistic regression models were used for analytic purposes. Chi-square tests were used to determine the association between categorical predictor variables and LBW and PTB, and univariate logistic regressions were used to assess the association between continuous predictor variables and the two birth outcomes. All predictor variables that had a statistically significant bivariate relationship with LBW and/or PTB ($p<0.05$) were subsequently included in the regression analyses. Moreover, because logistic regression is sensitive to high correlations among the predictor variables, the same variables that were used in the logistic regression models were entered into linear regression models to obtain collinearity diagnostics (i.e., Tolerance statistic, Variance inflation factor, Condition index) to assess multicollinearity. There were no high inter-correlations among the predictor variables.

The independent variables used to predict LBW and PTB were conceptualized and analyzed hierarchically into the following regression models: Model 1: Physical environment variables (e.g., exposure to sulfur dioxide, parks); Model 2: Model 1 plus demographic and SES variables (e.g., maternal age, neighborhood income); Model 3: Models 1-2 plus medical history variables (e.g., previous PTB, gestational diabetes); and Model 4: Models 1-3 plus behavioral risk factors (e.g., alcohol use, tobacco use).

Moderating effects were also assessed between air pollution and neighborhood income, and air pollution and infant gender, to examine their interaction effects with LBW and PTB. To improve the interpretation of the interaction and to avoid problems of multicollinearity, continuous variables were centered by subtracting the mean score from each data point, and then the residuals were multiplied together to create a centered product term (Aiken and West 1991). Statistical significance of all estimates was assessed at the $p<0.05$ level.

3. Results

3.1. Descriptive Results

Out of a total of 25,263 live births between February 2009 and February 2014 at LHSC, 5.7% were LBW and 7.5% were PTB. Women were, on average, 29.4 ± 5.4 years of age. The mean gestational age was 38.9 ± 2.0 weeks and the mean birthweight was 3387.2 ± 575.9 grams. Other select characteristics of the sample (e.g., SES, risk-taking behaviors) have been reported elsewhere [blinded].

Table 3 provides a descriptive analysis of the physical environment variables. The median sulfur dioxide concentration for maternal home postal codes was 0.12 ppb (IQR: 0.04, 0.25) and the mean ground-level ozone was 30.17 ppb ± 1.11. The mean fine particulates (PM2.5) was 7.56 µg/m³ ± 1.64, and the average normalized difference vegetation index (NDVI) within 1600m of a home postal code was 0.54 ± 0.08. About 39% of pregnant women lived within 200m of a major road or highway. The median network distance from home postal code to park/recreational land use was 1.10 km (IQR: 0.63, 2.13). The median number of variety and grocery stores within 1600m of maternal home postal codes were 2.00 (IQR: 0.00, 4.00) and 1.00 (IQR: 0.00, 2.00), respectively. The mean number of gas stations within 1600m of home postal codes was 3.39 ± 2.91.

3.2. Regression Analyses

Table 4 present the results of the logistic regression models estimating the relative effects of the physical environment, SES, clinical history of medical problems, and behavioral risk factors on the odds of mothers having a LBW infant. In Model 1, exposure to sulfur dioxide, ground-level ozone, number of variety stores within 500m of home postal code, and percentage of dwellings in need of major repair were all positively and significantly associated with having a LBW baby. There was an inverse relationship between NDVI within 1600m and LBW. In Model 2, the positive association between sulfur dioxide and LBW remained, as did the inverse correlation between NDVI within 1600m and LBW. Additionally, having an underweight pre-pregnancy BMI increased the likelihood of having a LBW baby, whereas recent immigration had the opposite effect. When medical history variables were added in Model 3, the only physical environment factor that remained positively correlated with LBW was sulfur dioxide. An underweight pre-pregnancy BMI increased the odds of a LBW baby, as did a previous PTB, pre-pregnancy asthma, pre-existing hepatitis B, pre-existing thyroid disease, and chronic hypertension. Maternal age and recent immigration were negatively correlated with LBW. In Model 4, sulfur dioxide remained the top physical environment variable associated with LBW. For every one-unit increase in sulfur dioxide, the odds of a LBW were 3.4 times higher (95% Confidence Interval (CI): 2.2, 5.2), after controlling for all other variables in the model ($p<0.001$). Since a one-unit increase in sulfur dioxide translates into a substantial increase in air pollution, the IQR was used as a scaling factor to reflect values of sulfur dioxide that are relatively common in the study. Adjusting for all the same variables in Model 4, an interquartile increase in exposure to sulfur dioxide was associated with a 30% increase in LBW (OR: 1.3, 95% CI: 1.2, 1.4; $p<0.001$). Other factors that were positively correlated with LBW included: underweight pre-pregnancy BMI, previous PTB, pre-pregnancy asthma, pre-existing hepatitis B, pre-existing thyroid disease, chronic hypertension, gestational diabetes, marijuana use, and tobacco use. The proportion of recent immigrants in the neighborhood was inversely related to LBW.

Table 5 presents the results of the hierarchical logistic regression models for PTB, the findings of which resemble those of LBW. Sulfur dioxide was the only environmental factor associated with PTB across the four models. Like the LBW model, the effect size for sulfur dioxide and PTB is large. Model 4 shows that, for every unit increase in exposure to sulfur dioxide, pregnant women were 2.0 times more likely to have a have a PTB (95% CI: 1.4, 3.0) after controlling for all other variables in the model ($p<0.001$). Using IQR scaling, pregnant women are 1.2 times more likely (95% CI: 1.1, 1.3) to have a PTB for every interquartile increase in exposure to sulfur dioxide, adjusting for all the same variables in Model 4 ($p<0.001$). Other variables associated with PTB were: low immigration and visible minority prevalence, underweight pre-pregnancy BMI, previous PTB, anxiety during pregnancy, pre-pregnancy asthma, pre-existing thyroid disease, and gestational diabetes. Unexpectedly, smoking tobacco while pregnant decreased the odds of a PTB ($p<0.05$).

3.3. Interactions of Sulfur Dioxide with Neighborhood Income and Gender

Two statistical interaction effects were also explored in this study. First, given the importance of studying the physical environment and SES together, and the recommendation to examine interactions between the physical environment and SES (Genereux et al. 2008; Zeka et al. 2008), effect modification was assessed by examining the interaction between exposure to sulfur dioxide and neighborhood income on adverse birth outcomes. Second, because the findings from a systematic review suggest that the interactive effects of air pollution and gender on birth outcomes remains unclear (Ghosh et al. 2007), an interaction term was computed for exposure to sulfur dioxide and biological sex of the infant. No interactions were statistically significant (data not shown).

4. Discussion

Although evidence is accumulating on the effects of air pollution on adverse birth outcomes, most studies have been conducted in geographically distinct areas with high levels of air pollution and are not able to adjust for important covariates that are also known to be associated with birth outcomes (Yorifuji et al. 2015). In the current study of pregnant women from SWO, we took advantage of a large neonatal and perinatal database, and through geographical mapping of maternal postal codes, could test the relative influence of environmental, sociodemographic, medical, and behavioral factors associated with LBW and PTB. While there were several key factors associated with both birth outcomes, the impact of sulfur dioxide exposure cannot be overstated. The odds of women having a LBW and PTB were 3.4 and 2.0 for every one-unit increase in sulfur dioxide exposure in ppb, adjusting for all other covariates in the regression analysis. This translates into a 30% and 20% increase in LBW and PTB, respectively, for an interquartile range increase in exposure to sulfur dioxide. About two-thirds (66%) of sulfur dioxide emission in Ontario in 2012 came from smelters and utilities; 26% from other sulfur dioxide industrial sources; 5% from transportation; 4% from utilities; and 3% miscellaneous/residential (Ontario Ministry of the Environment, Conservation and Parks, 2018a). Also, because collinearity between pollutants was not a problem in our study, we were able to delineate the primary role of sulfur dioxide on LBW and PTB. This is the first study in SWO to investigate the association between air pollution and adverse birth outcomes.

Other research that has examined the impact of sulfur dioxide on adverse birth outcomes has produced mixed results, with some studies showing a significant correlation with poor birth outcomes (Boback 2000; Brauer et al. 2018; Ha et al. 1997; Lin et al. 2004; Sagiv et al. 2005; Wang et al. 1997; Yorifuji et al. 2015) and others showing no effect (Dugandzic et al. 2006; Green et al. 2015; Liu et al. 2007). In their systematic review of individual air pollutiants, Shah and Balkhair (2011) assessed 19 studies on birth outcomes following exposure to sulfur dioxide; only 6/17 studies (35%) reported an increased odds of LBW, although 4/5 studies (80%) showed an increased odds of PTB. The authors argue that a key methodological problem with many studies is that they do not consider other determinants of health, including socioeconomic, psychosocial, and behavior-related factors which are also associated with birth outcomes. These factors are all present in the current study, along with many important medical history variables as well.

Although not specific to sulfur dioxide, research is accumulating on the association between air pollution and pregnancy outcomes in Canada. In a study of about 3 million singleton live births in Canada between 1999 and 2008 which included urban and rural areas, a 10-μg/ increase in PM2.5 over the entire pregnancy was associated with small for gestational age (SGA) [odds ratio (OR) = 1.04; 95% CI: 1.01, 1.07] and reduced term birth weight (OR = –20.5 g; 95% CI: –24.7, –16.4) in fully adjusted models (Stieb et al.

2016). Interestingly, however, a 10-µg/ increase in PM2.5 had a statistically significant negative association with PTB over the entire pregnancy (OR = 0.96; 95% CI: 0.93, 0.99), and the authors speculate that this may be due to bias or residual confounding. Similarly, in a population-based cohort study of 64,705 singleton births (1990-2002) from Vancouver, British Columbia, increased greenness within 100 m of residences was associated with higher term birth weight and lower risk for SGA and very preterm (<30 weeks) and moderately (30-36 weeks) PTB, even after adjustment for air pollution (Hystad et al. 2014). Furthemore, low to moderate negative correlations were found between NDVI levels and exposure to nitric oxide, nitrogen dioxide, fine particulate matter, and black carbon, suggesting that greenness may reduce harmful environmental exposures.

Another interesting finding from the current study was that maternal neighborhood SES did not modify the relationship between exposure to sulfur dioxide and adverse birth outcomes. While this was somewhat unexpected, a study from Montreal, Canada showed that mothers from disadvantaged neighborhoods who lived close to highways were not more likely to have LBW, PTB, or small-for-gestational-age babies (Genereux et al. 2008). With little research on the health effects of disadvantaged neighborhoods in Canada compared to the United States, it is possible that differing levels of neighborhood income inequality between the two countries (Ross et al. 2000; Seabrook and Avison 2015) may be the reason that there was no significant moderation effect. A systematic review and meta-analysis found that, compared to women living in the most affluent neighborhoods in the United States, mothers living in the most disadvantaged neighborhoods had an 11% and 27% higher risk for LBW and PTB, respectively, although there was no association between birth outcomes and neighborhood disadvantage in studies that adjusted for race (Ncube et al. 2016). It may also be that Canada's universal health care system protects pregnant women living in economically-deprived areas who are exposed to differing levels of air pollution. In fact, another study from Montreal found that neighborhood SES contributed to only 3% of the variation in health status, despite Montreal having the highest level of income inequality of all major cities in Canada (Ross et al. 2004).

It is also noteworthy that, for both the LBW and PTB regression models, recent immigration decreased the odds of having an adverse birth outcome. It is possible that this may have to do with the "healthy immigrant effect," whereby immigrants have better overall health on arrival to Canada compared to native-born residents, although the health advantage attenuates with more years spent in the country (McDonald and Kennedy, 2004). Moreover, our research adds to the few other Canadian studies that have investigated the influence of immigration on birth outcomes. In a population-based cross-sectional study from Toronto, Ontario, recent immigration was associated with a lower risk of PTB but a higher risk for LBW (Urquia et al. 2007). In metropolitan areas of Ontario, recent immigrants had a lower risk of PTB than non-immigrants (Urquia et al. 2010), and in Quebec, the more acculturated women had higher rates of term LBW than did recent immigrants (Hyman and Dussault 1996). Our results largely coincide with these other studies, except for the Toronto study which showed a higher risk for LBW among recent immigrants.

The current study has a few limitations. First, our measure of exposure to sulfur dioxide was based on a 3-year running average, and a median of 0.12 ppb in SWO indicates good air quality. While there were no areas in SWO with high 3-year average concentrations, there were individual days with moderate to high levels of sulfur dioxide where pregnant women should be limiting their exposure outdoors. Second, maternal postal codes may not be reflective of place of residence for the entire pregnancy. For example, higher rates of mobility during pregnancy have been reported among women with low SES, although most moves are over very short distances, typically within the same municipality (Fell et al. 2004). Third, workplace exposure to air pollution was not available, as our data only contained information on residential postal codes. However, recent research has found negligible differences in the effect size of LBW and PTB when including workplace exposure to air pollution compared to residential exposure only (Dibben and Clemens 2015). Fourth, while many studies have not adjusted for the effect of maternal smoking on adverse birth outcomes (Li et al. 2017; Shah and Balkhair 2011), we were able to do so, but we were not able to capture frequency or quantity of smoking. Maternal smoking (and all individual-level drug use variables for that matter) was self-reported data, where women were simply asked after birth whether they had smoked during their pregnancy. Nevertheless, it is noteworthy that the effect size for LBW was greater for sulfur dioxide than for smoking (OR: 3.4 vs. 1.5); similarly, sulfur dioxide had a larger influence on PTB than did smoking while pregnant (OR: 2.0 vs. 0.73). Fifth, Canadian postal codes are more restricted than American zip codes because the former geocode to point locations (Krieger et al. 2003). Healy and Gilliland (2012) show that postal code proxies based on DAs can result in large positional discrepancies in rural areas, although they are reasonable proxies for residential addresses in suburban and urban areas. Fortunately, 87% of our sample lived in areas with high resolution of postal code data, and for those living in rural areas, CANUE has weighted the location of postal code centroids to best represent the spatial distribution of the population in each postal code so that potential exposure misclassification will be minimized (CANUE, 2018).

5. Conclusion

This large-scale study provides evidence of a strong association between exposure to sulfur dioxide during pregnancy and adverse birth outcomes. Health care providers should be informed about the hazards of air pollution to developing fetuses so that adequate recommendations can be made to their pregnant patients on staying indoors with the windows closed, or taking other means to limit exposure when local air quality is poor. Future studies could assess whether seasonal variation in exposure to air pollution acts as potential confounder or effect modifier in the association between air pollution and adverse birth outcomes. More research should also investigate whether the timing of environmental exposures during pregnancy (i.e., by trimester) is associated with adverse birth outcomes, as findings to date in this area have remained largely inconclusive (Bonzini et al. 2010).

Acknowledgements

This work was supported by a Brescia University College research grant and trainee support from the Children's Health Foundation through the Children's Health Research Institute.

The authors acknowledge postal code data were provided by DMTI Spatial Inc, via the Canadian Urban Environmental Health Research Consortium (CANUE) under the current Data Liberation Initiative in place with Canadian Universities. Nearest attributes for pollution data were calculated and appended by CANUE staff. Postal code level socioeconomic data were calculated and appended by Human Environments Analysis

Lab (HEAL) using publicly-available data from the National Household Survey of Canada, 2011. The authors thank Environment and Climate Change Canada for the provision of ground-level SO_2 and Ozone data, which were accessed via CANUE. $PM_{2.5}$ data were provided by the Atmospheric Composition Analysis Group at Dalhousie University, Halifax, Canada (http://fizz.phys.dal.ca/~atmos/martin/?page_id=140). SO_2, Ozone, and $PM_{2.5}$ data were all indexed to DMTI Spatial Inc. postal codes by CANUE.

Declaration of Interests: None

Disclosure

The authors have no conflicts of interest to declare.

References

Aiken LS, West SG. 1991. *Multiple regression: Testing and interpreting interactions*. Thousand Oaks, CA: Sage Publications Inc.

Barker DJP. 2004. The developmental origins of chronic adult disease. J Am Coll Nutr 23(6):588S–595S. PMID: 15702667, 10.1111/j.1651-2227.2004.tb00236.x.

Bobak M. 2000. Outdoor air pollution, low birth weight, and prematurity. Environ Health Perspect 108(2):173-176. PMID: 10656859, 10.2307/3454517.

Bonzini M, Carugno M, Grillo P, Mensi C, Bertazzi PA, Pesatori AC. 2010. Impact of ambient air pollution on birth outcomes: systematic review of the current evidences. La Medicina del lavoro 101(5):341-363.

Boys BL, Martin RV, van Donkelaar A, MacDonell R, Hsu NC, Cooper MJ, et al. 2014. Fifteen-year global time series of satellite-derived fine particulate matter. Environ Sci Technol 48(19):11109-11118. PMID: 25184953, 10.1021/es502113p.

Brauer M, Lencar C, Tamburic L, Koehoorn M, Demers P, Karr C, et al. 2018. A cohort study of traffic-related air pollution impacts on birth outcomes. Environ Health Perspect 116(5):680–686. PMID: 18470315, 10.1289/ehp.10952.

Campbell E, Seabrook J. 2018. The influence of socioeconomic status on adverse birth outcomes. Can J Midwifery Res Pract 15:10–20.

Campbell EE, Gilliland J, Dworatzek PDN, de Vrijer B, Penava D, Seabrook JA. 2018. Socioeconomic status and adverse birth outcomes: A population-based Canadian sample. J Biosoc Sci 50(1):102-113. PMID: 28270256, 10.1017/S0021932017000062.

Canadian Urban Environmental Health Research Consortium. 2018. http://canue.ca/wp-content/uploads/2018/03/CANUE-Metadata-PostalCodes-1.pdf [accessed 1 February 2018].

CanMap Content Suite [computer file]. 2015. Markham, Ontario: DMTI Spatial Inc.

CanMap Postal Code Suite v2015.3. 2015. [computer file] Markham: DMTI Spatial Inc.

CanMap Postal Code Suite v2016.3. 2016. [computer file] Markham: DMTI Spatial Inc.

Dadvand P, de Nazelle A, Triguero-Mas M, Schembari A, Cirach M, Amoly E, et al. 2012. Surrounding greenness and exposure to air pollution during pregnancy: an analysis of personal monitoring data. Environ Health Perspect 120(9):1286‑1290. PMID: 22647671, 10.1289/ehp.1104609.

Dibben C, Clemens T. 2015. Place of work and residential exposure to ambient air pollution and birth outcomes in Scotland, using geographically fine pollution climate mapping estimates. Environ Res 140:535-541. PMID: 26005952, 10.1016/j.envres.2015.05.010.

DMTI CanMap Route Logistics [computer file]. 2015. Markham, Ontario: DMTI Spatial Inc.

DMTI Enhanced Points of Interest (EPOI) [computer file]. 2015. Markham, Ontario: DMTI Spatial Inc.

Dugandzic R, Dodds L, Stieb D, Smith-Doiron M. 2006. The association between low level exposures to ambient air pollution and term low birth weight : a retrospective cohort study. Environ Health 5:3. PMID: 16503975, 10.1186/1476-069X-5-3.

Environment and Climate Change Canada. 2017. Air Quality Research Division, Toronto, Canada. Data files: GEMMACH_Ground-Level_O3_NA_2010.nc to GEMMACH_Ground-Level_O3_NA_2015.nc inclusive, generated July 2017.

Environment and Climate Change Canada. 2017. Air Quality Research Division, Toronto, Canada. Data files: OMI_Ground-Level_SO2_NA_2005.nc to OMI_Ground Level_SO2_NA_2015.nc inclusive, generated 2017-07-05.

Fell DB, Dodds L, King WD. 2004. Residential mobility during pregnancy. Paediatr Perinat Epidemiol 18(6):408-414. PMID: 15535816, 10.1111/j.1365-3016.2004.00580.x.

Genereux M, Auger N, Goneau M, Daniel M. 2008. Neighbourhood socioeconomic status, maternal education and adverse birth outcomes among mothers living near highways. J Epidemiol Community Health 62(8):695-700. PMID: 18621954, 10.1136/jech.2007.066167.

Ghosh R, Rankin J, Pless-Mulloli T, Glinianaia S. 2007. Does the effect of air pollution on pregnancy outcomes differ by gender? A systematic review. Environ Res 105(3):400–408. PMID: 17493608, 10.1016/j.envres.2007.03.009.

Glinianaia SV, Rankin J, Bell R, Pless-Mulloli T, Howel D. 2004. Particulate air pollution and fetal health: a systematic review of the epidemiologic evidence. Epidemiology 15(1):36–45. PMID: 14712145 DOI: 10.1097/01.ede.0000101023.41844.ac.

Green R, Sarovar V, Malig B, Basu R. 2015. Association of stillbirth with ambient air pollution in a California cohort study. Am J Epidemiol 181(11):874–882. PMID: 25861815, 10.1093/aje/kwu460.

Ha E, Hong Y, Lee B, Woo B, Schwartz J, Christiani DC. 1997. Is air pollution a risk factor for low birth weight in Seoul? Epidemiology 12(6):643–648. PMID: 11679791, 10.1097/00001648-200111000-00011.

Hyman I, Dussault G. 1996. The effect of acculturation on low birthweight in immigrant women. Can J Public Health 87(3): 158-162. PMID: 8771915.

Hystad P, Davies HW, Frank L, Van Loon J, Gehring U, Tamburic L, et al. 2014. Residential greenness and birth outcomes: evaluating the influence of spatially correlated built-environment factors. Environ Health Perspect122(10):1095-1102. PMID: 25014041, 10.1289/ehp.1308049.

Kharol SK, McLinden CA, Sioris CE, Shephard MW, Fioletov V, van Donkelaar A, et al. 2017. OMI satellite observations of decadal changes in ground-level sulfur dioxide over North America. Atmos Chem Phys 17(9):5921-5929. doi:10.5194/acp-17-5921-2017.

Krieger N, Chen JT, Waterman PD, Soobader MJ, Subramanian SV, Carson R. 2003. Choosing area based socioeconomic measures to monitor social inequalities in low birth weight and childhood poisoning: the public health disparities geocoding project (US). J Epidemiol Community Health 57(3):186–199. PMID: 12594195, 10.1136/jech.57.3.186.

Lacasana M, Esplugues A, Ballester F. 2005. Exposure to ambient air pollution and prenatal and early childhood health effects. Eur J Epidemiol 20(2):183–199. PMID: 15792286, 10.1007/s10654-004-3005-9.

Lackmann F, Capewell V, Richardson B. 2001. The risks of spontaneous preterm delivery and perinatal mortality in relation to size at birth according to fetal versus neonatal growth standards. Am J Obstet Gynecol 184(5):946–953. PMID: 11303203, 10.1067/mob.2001.111719.

Lamichhane DK, Leem JH, Lee JY, Kim HC. 2015. A meta-analysis of exposure to particulate matter and adverse birth outcomes. Environ Health Toxicol 30: e2015011. PMID: 26796890, 10.5620/eht.e2015011.

Li X, Huang S, Jiao A, Yang X, Yun J, Wang Y, et al. 2017. Association between ambient fine particulate matter and preterm birth or term low birth weight: An updated systematic review and meta-analysis. Environ Pollut 227:596-605. PMID: 28457735, 10.1016/j.envpol.2017.03.055.

Lin C, Li C, Yang G, Mao I. 2004. Association between maternal exposure to elevated ambient sulfur dioxide during pregnancy and term low birth weight. Environ Res 96(1):41–50. PMID: 15261783, 10.1016/j.envres.2004.03.005.

Liu S, Krewski D, Shi Y, Chen Y, Burnett RT. 2007. Association between maternal exposure to ambient air pollutants during pregnancy and fetal growth restriction. J Expo Sci Environ Epidemiol 17(5):426–432. PMID: 16736056, 10.1038/sj.jes.7500503.

Maisonet M, Correa A, Misra D, Jaakkola JJ. 2004. A review of the literature on the effects of ambient air pollution on fetal growth. Environ Res 95(1):106–115. PMID: 15068936, 10.1016/j.envres.2004.01.001.

McDonald JT, Kennedy S. 2004. Insights into the 'healthy immigrant effect': health status and health service use of immigrants to Canada. Soc Sci Med 59(8):1613-1627. PMID: 15279920, 10.1016/j.socscimed.2004.02.004.

McLinden CA, Fioletov V, Boersma KF, Kharol SK, Krotkov N, Lamsal L, et al. 2014. Improved satellite retrievals of NO2 and SO2 over the Canadian oil sands and comparisons with surface measurements, Atmos Chem Phys 14(7):3637-3656. doi:10.5194/acp-14-3637-2014, 2014.

Nowak AL, Giurgescu C. 2017. The built environment and birth outcomes: a systematic review. MCN Amer J Matern Child Nurs 42(1):14-20. PMID: 27755063, 10.1097/NMC.0000000000000299.

Ncube CN, Enquobahrie DA, Albert SM, Herrick AL, Burke JG. 2016. Association of neighborhood context with offspring risk of preterm birth and low birthweight: A systematic review and meta-analysis of population-based studies. Soc Sci Med 153:156-64. PMID: 26900890, 10.1016/j.socscimed.2016.02.014.

Ontario Ministry of the Environment, Conservation and Parks. 2018a. http://www.airqualityontario.com/science/pollutants/sulphur.php [Accessed 26 October 2018].

Ontario Ministry of the Environment, Conservation and Parks, 2018b. http://www.airqualityontario.com/science/pollutants/ozone.php [Accessed 26 October 2018].

Ontario Ministry of the Environment, Conservation and Parks, 2018c. http://airqualityontario.com/science/pollutants/particulates.php [Accessed 26 October 2018].

Phelan JC, Link BG, Tehranifar P. 2010. Social conditions as fundamental causes of health inequalities: theory, evidence, and policy implications. J Health Soc Behav 51Suppl:S28-S40. PMID: 20943581, 10.1177/0022146510383498.

Rhew IC, Stoep AV, Kearney A, Smith NL, Dunbar MD. 2011. Validation of the normalized difference vegetation index as a measure of neighborhood greenness. Ann Epidemiol 21(12):946–952. PMID: 21982129, 10.1016/j.annepidem.2011.09.001.

Ritz B, Wilhelm M. 2008. Ambient air pollution and adverse birth outcomes: methodologic issues in an emerging field. Basic Clin Pharmacol Toxicol 102(2):182-190. PMID: 18226073, 10.1111/j.1742-7843.2007.00161.x.

Robichaud A, Ménard R. 2014. Multi-year objective analyses of warm season ground-level ozone and PM 2.5 over North America using real-time observations and Canadian operational air quality models. Atmos Chem Phys 14(4):1769-1800. 10.5194/acp-14-1769-2014.

Robichaud A, Ménard R, Zaïtseva Y, Anselmo D. 2016. Multi-pollutant surface objective analyses and mapping of air quality health index over North America. Air Qual Atmos Health 9(7):743-745. PMID: 27785157, 10.1007/s11869-015-0385-9.

Ross NA, Tremblay S, Graham K. 2004. Neighbourhood influences on health in Montreal, Canada. Soc Sci Med 59(7):1485–1494. PMID: 15246176, 10.1016/j.socscimed.2004.01.016.

Ross NA, Wolfson MC, Dunn JR, Berthelot JM, Kaplan GA, Lynch JW. 2000. Relation between income inequality and mortality in Canada and in the United States: cross sectional assessment using census data and vital statistics. BMJ 320(7329):898–902. PMID: 10741994, 10.1136/bmj.320.7239.898.

Sagiv SK, Mendola P, Loomis D, Herring AH, Neas LM, Savitz DA, et al. 2005. A time series analysis of air pollution and preterm birth in Pennsylvania, 1997–2001. Environ Health Perspect 113(5):602-606. PMID: 15866770, 10.1289/ehp.7646.

Seabrook JA, Avison WR. 2015. Family structure and children's socioeconomic attainment: a Canadian sample. Can Rev Sociol 52(1):66-88. PMID: 25737465, 10.1111/cars.12061.

Seabrook JA, Avison WR. 2012. Socioeconomic status and cumulative disadvantage processes across the life course: implications for health outcomes. Can Rev Sociol 49(1):50-68. PMID: 22586837, 10.1111/j.1755-618X.2011.01280.x.

Seabrook JA, Woods N, Clark A, de Vrijer B, Penava D, Gilliland J. 2018. The association between alcohol outlet accessibility and adverse birth outcomes: A retrospective cohort study. J Neonatal Perinatal Med 11(1):71-8. PMID: 29689749, 10.3233/NPM-181741.

Statistics Canada. 2011. Census of Canada, 2011. Statistics Canada, Government of Canada.

Shah PS, Balkhair T, Knowledge Synthesis Group on Determinants of Preterm/LBW births. 2011. Air pollution and birth outcomes: a systematic review. Environ Int 37(2):498-516. PMID: 21112090, 10.1016/j.envint.2010.10.009.

Sram RJ, Binkova B, Dejmek J, Bobak M. 2005. Ambient air pollution and pregnancy outcomes: a review of the literature. Environ Health Perspect 113(4):375–382. PMID: 15811825, 10.1289/ehp.6362.

Stieb DM, Chen L, Beckerman BS, Jerrett M, Crouse DL, Omariba DW, et al. 2015. Associations of pregnancy outcomes and PM2. 5 in a national Canadian study. Environ Health Perspect 124(2):243-249. PMID: 26090691, 10.1289/ehp.1408995.

United States Geological Survey. 2016. USGS Earth Explorer; United States Geological Survey: Reston, VA, USA.

Urquia ML, Frank JW, Glazier RH, Moineddin R. 2007. Birth outcomes by neighbourhood income and recent immigration in Toronto. Health Rep 18(4):21-30. PMID: 18074994.

Urquia ML, Frank JW, Moineddin R, Glazier RH. 2010. Immigrants' duration of residence and adverse birth outcomes: a population- based study. BJOG 117(5):591-601. PMID: 20374596, 10.1111/j.1471-0528.2010.02523.x.

van Donkelaar A, Martin RV, Spurr RJ, Burnett RT. 2015. High-resolution satellite-derived PM2.5 from optimal estimation and geographically weighted regression over North America. Environ Sci Technol 49(17):10482-10491. PMID: 26261937, 10.1021/acs.est.5b02076.

Van Lieshout RJ, Boyle MH, Saigal S, Morrison K, Schmidt LA. 2015. Mental health of extremely low birth weight survivors in their 30s. Pediatrics 135(3):452-459. PMID: 25667243, 10.1542/peds.2014-3143.

Wang X, Ding H, Ryan L, Xu X. 1997. Association between air pollution and low birth weight: a community-based study. Environ Health Perspect 105(5):514-520. PMID: 9222137, 10.1542/peds.2014-3143.

Ward Thompson C, Roe J, Aspinall P, Mitchell R, Clow A, Miller D. 2012. More green space is linked to less stress in deprived communities: evidence from salivary cortisol patterns. Lands Urban Plann 105(3):221‑229. 10.1016/j.landurbplan.2011.12.015.

Woods N, Gilliland J, Seabrook JA. 2017. The influence of the built environment on adverse birth outcomes. J Neonatal Perinatal Med 10(3):233-248. PMID: 28854508,10.3233/NPM-16112.

World Health Organization. 2018. http://www.who.int/en/news-room/fact-sheets/detail/preterm-birth [accessed 19 May 2018].

Yorifuji T, Kashima S, Doi H. 2015. Outdoor air pollution and term low birth weight in Japan. Environ Int 74:106–111. PMID: 25454226, 10.1016/j.envint.2014.09.003.

Zeka A, Melly SJ, Schwartz J. 2008. The effects of socioeconomic status and indices of physical environment on reduced birth weight and preterm births in Eastern Massachusetts. Environ Health 7:60. PMID: 19032747, 10.1186/1476-069X-7-60.

Table 1. Full list of independent variables used to assess their relationship with low birth weight and preterm birth.

Physical Environmental Variables	**Demographic and Socioeconomic Variables**	**Medical History Variables**	**Behavioral Risk Factor Variables**
Sulfur dioxide (SO_2)	Pre-pregnancy body mass index	Previous preterm birth	No antenatal care provider
Ground-level ozone (O_3)	Maternal age	Anxiety this pregnancy	Marijuana use during pregnancy
Fine particulates ($PM_{2.5}$)	Maternal education	Depression this pregnancy	Smoked tobacco during pregnancy
National highway	Population density	Pre-pregnancy asthma	Alcohol use during pregnancy
Major road	Recent immigration prevalence	Pre-existing heart disease	Opioid use during pregnancy
Park and recreational land use	Visible minority prevalence	Pre-existing hepatitis B	Narcotic use during pregnancy
Gas stations	Aboriginal prevalence	Pre-existing lupus	Herbal medicine use during pregnancy
Power lines	Low-income measure after-tax	Pre-existing thyroid disease	Amphetamine use during pregnancy
Industrial land use	Lone-parent families	Pre-existing insulin-dependent diabetes	Intention to breastfeed
Closest park and recreational land use		Chronic hypertension	
Closest variety store		Gestational diabetes	

Closest grocery store	Infant gender at birth
Presence of major road or highway	
Number of gas stations	
Number of variety stores	
Park and recreational land use ratio	
Dwellings in need of major repair	
Normalized difference vegetation index	

Table 2. Environmental variables and a description of their measurement.

Variables	**Description**
Pollution Measures	Pollution data was made available through the CANUE Consortium (www.canue.ca).
Sulfur dioxide (SO_2)	3-year running average (2013-2015) of ground-level sulfur dioxide concentrations in parts per billion (ppb) by postal code were estimated from the Ozone Monitoring Instrument satellite data using SO_2 profiles from the Global Environmental Multi-scale (Environment and Climate Change Canada, 2017; McLinden et al, 2014; Kharol et al, 2015). The multi-year mean is used for better representation of ground-level concentrations, as recommended by Kharol et al. (2017). The spatial resolution of the data is 20-km, which is sufficient when trying to understand the impact that a non-point source pollutant has on health outcomes. Ontario SO_2 Emissions by Sector - 2012 Estimates: Smelters (62%), other SO_2 industrial sources (26%), transportation 5%, utilities 4%, miscellaneous/residential 3% (Ontario Ministry of the Environment, Conservation and Parks, 2018a).
Ground-level ozone (O_3)	Ground-level ozone (O3) concentration in ppb by postal code were estimated with Global Environmental Multi-scale Modelling Air Quality and Chemistry model (Environment and Climate Change, 2017; Robichaud & Ménard, 2014; Ménard, Zaïtseva, & Anselmo, 2016). The spatial resolution of the data is 10-km and only includes an average over a year, which is sufficient when trying to understand the impact that a non-point source pollutant has on health outcomes. Ontario Volatile Organic Compounds Emissions by Sector - 2012 Estimates: General solvent use 25%, other transportation 24%, printing/surface coating 15%, industrial 13%, road vehicles 11%, residential 9%, miscellaneous 3% (Ontario Ministry of the Environment, Conservation and Parks, 2018b).
Fine particulates ($PM_{2.5}$)	3-year annual average (2012) of ground-level fine particulate matter ($PM_{2.5}$) concentration in micrograms per cubic meter by postal code was estimated by combining a 0.01 degree by 0.01 degree or 1-km spatial resolution optimal estimate-based Aerosol Optical Depth (AOD) retrieval from the NASA MODIS

	instrument with aerosol vertical profile and scattering properties simulated by the GEOS-Chem chemical transport model (Boys et al, 2014). Then, a geographically-weighted regression (GWR) that incorporates ground-based observations to adjust for any residual bias in the satellite-derived $PM_{2.5}$ estimates were applied (van Donkelaar et al, 2015). The smaller spatial resolution is important as PM2.5 is a point source pollutant that has much more local variation. van Donkelaar et al (2015) have used these measures to assess health effects on long-term exposure. Ontario Fine Particulate Matter Emissions by Sector - 2012 Estimates: Residential 39%, other transportation 19%, other $PM_{2.5}$ industrial processes 15%, smelters/primary metals 11%, miscellaneous 8%, cement and concrete industry 5%, road vehicles 3% (Ontario Ministry of the Environment, Conservation and Parks, 2018c).
Euclidean Distance Measures	Each of these variables measure the straight-line (Euclidean) distance in kilometres between maternal postal codes and the feature of interest using ArcMap 10.4.
National Highway	Euclidean distance to closest National Highway segment (DMTI, Spatial Inc., 2015a).
Major road	Euclidean distance to closest major road segment (DMTI, Spatial Inc., 2015a), including major highways, secondary highways, and major streets.
Park and recreation land use	Euclidean distance to closest park and recreation land use (DMTI, Spatial Inc, 2015a).
Gas stations	Euclidean distance to closest gas station (DMTI, Spatial Inc, 2015c).
Power lines	Euclidean distance to closest power line (DMTI, Spatial Inc, 2015a).
Industrial land use	Euclidean distance to closest industrial land use (DMTI, Spatial Inc, 2015a).
Network Distance Measures	Each of these variables use ArcMap 10.4 to measure the shortest network distance in kilometres between maternal postal codes and the feature of interest using the street network file provided by DMTI, Spatial Inc (2015b).
Closest park and recreation land use	Network distance to closest park and recreation land use (DMTI, Spatial Inc, 2015a).
Closest variety store	Network distance to closest variety store location (DMTI, Spatial Inc, 2015c).
Closest grocery store	Network distance to closest grocery store (DMTI, Spatial Inc, 2015c).
Others	
Presence of major road or highway	A major road or highway (DMTI, Spatial Inc., 2015a) is located within a 200-metre Euclidean distance of a postal code (1) or not (0).
Number of gas stations	Number of gas stations (DMTI, Spatial Inc, 2015c) located within 500-metre and 1,600 Euclidean distance of a postal code.
Number of variety stores	Number of variety stores (DMTI, Spatial Inc, 2015c) located within 500-metre and 1,600-metre network distance of a postal code.
Number of grocery stores	Number of grocery stores (DMTI, Spatial Inc, 2015c) located within 500-metre and 1,600-metre network distance of a postal code.

Park and recreational land use ratio	Percentage of park and recreation land use to all land uses (DMTI, Spatial Inc, 2015a) within 500-metre Euclidean distance of a postal code.
Normalized difference vegetation index (NDVI)	A measure of greenness (Rhew et al. 2011) computed from the 2013 Landsat 8 satellite imagery (United States Geological Survey, 2016). NDVI variables were calculated from images with a 30-meter resolution, with values averaged across a 500-meter and 1,600-meter buffer, where higher values indicate more green space. All images were extracted during summer months to maximize green coverage in study areas.
Dwellings in need of major repair	Percentage of dwellings in need of major repair within a mother's neighborhood (Statistics Canada, 2011).

Table 3. Descriptive Statistics on Physical Environment Variables

Variables	Measure of Central Tendency*
Sulfur dioxide (ppb)	0.12 (0.04, 0.25)
Ground-level ozone (ppb)	30.17 ± 1.11
Fine particulates (PM2.5, micrograms per cubic meter)	7.56 ± 1.64
Euclidean distance home postal code to highways (km)	5.92 (3.23, 9.20)
Euclidean distance home postal code to major roads (km)	0.27 (0.12, 0.52)
Presence of major road/highway within 200 m of home (%)	38.5
Euclidean distance home postal code to park/recreation use (km)	0.73 (0.41, 1.40)
Network distance home postal code to park/recreation use (km)	1.10 (0.63, 2.13)
500m buffer covered in park/recreational land (%)	0.10 (0.00, 3.94)
Average normalized difference vegetation index (500m of home)	0.50 ± 0.09
Average normalized difference vegetation index (1600m of home)	0.54 ± 0.08
Network distance home postal code to variety store (km)	1.30 (0.68, 2.52)
Number of variety stores within 500m of home postal code	0.00 (0.00, 1.00)
Number of variety stores within 1600m of home postal code	2.00 (0.00, 4.00)
Network distance home postal code to grocery store (km)	1.48 (0.91, 2.71)
Number of grocery stores within 500m of home postal code	0.00 (0.00, 0.00)
Number of grocery stores within 1600m of home postal code	1.00 (0.00, 2.00)
Euclidean distance home postal code to gas stations (km)	0.88 (0.52, 1.38)
Euclidean distance home postal code to power line (km)	2.39 (1.25, 4.58)

Euclidean distance home postal code to industrial land use (km)	0.52 (0.19, 1.20)
Euclidean distance home postal code to gas stations (km)	0.88 (0.52, 1.38)
Number of gas stations within 500m of home postal code	0.00 (0.00, 0.00)
Number of gas stations within 1600m of home postal code	3.39 ± 2.91
Dwellings in need of major repair (%)	0.00 (0.00, 7.46)

*Data are expressed as mean ± SD, median (25th, 75th percentiles), or percentages.

Table 4. Logistic Regression Assessing the Relative Effects of the Physical Environment, Socioeconomic Status, Clinical History of Medical Problems, and Behavioral Risk Factors on Mothers Having a Low Birth Weight Infant

	Model 1		Model 2		Model 3		Model 4	
	B	OR	b	OR	b	OR	b	OR
Sulfur dioxide	1.426***	4.162	1.429***	4.174	1.183***	3.266	1.209***	3.351
Ground-level ozone	.093**	1.097	.041	1.042	.028	1.029	.024	1.024
# of grocery stores within 1600m	.017	1.017	.006	1.006	.023	1.023	.029	1.029
# of variety stores within 500m	.073*	1.076	.004	1.045	.024	1.025	.036	1.036
% of dwellings in need of major repair	.008*	1.008	.000	1.000	.002	1.002	.002	1.002
NDVI within 1600m	-2.057***	.128	-1.667*	.189	-1.444	.236	-1.332	.264
Underweight pre-pregnancy BMI			.715***	2.044	.746***	2.109	.681***	1.976

Maternal age	-.004	.996	-.019*	.982	-.007	.993
% ≤ high school diploma	.008	1.008	.005	1.005	.003	1.003
Population density	-.029	.972	-.032	.969	-.026	.974
% immigrants	-.044**	.957	-.040*	.960	-.040*	.961
% visible minorities	.001	1.001	.003	1.003	.005	1.005
% aboriginal	.000	1.000	.000	1.000	-.002	.998
% low income	.006	1.006	.005	1.005	.004	1.004
% lone-parent families	.001	1.001	-.001	.999	-.002	.998
Previous preterm birth			1.280***	3.597	1.236***	3.441
Anxiety this pregnancy			.011	1.011	.122	1.130
Pre-pregnancy asthma			.430**	1.537	.418**	1.519
Pre-existing heart disease			.216	1.241	.314	1.369
Pre-existing hepatitis B			1.321**	3.747	1.338*	3.812
Pre-existing lupus			-.256	.774	-.170	.843
Pre-existing thyroid disease			.414*	1.513	.394*	1.482
Depression this pregnancy			.262	1.299	.142	1.152
Pre-existing insulin-dependent diabetes			.042	1.043	-.151	.860
Chronic hypertension			.972***	2.642	1.049***	2.855
Infant gender			-.142	.868	-.172	.842

Gestational diabetes					.345	1.412	.419*	1.521
No antenatal care provider							-.127	.881
Marijuana use during pregnancy							.860***	2.363
Smoked during pregnancy							.399**	1.490
Alcohol use during pregnancy							-.561	.571
Opioid use during pregnancy							.296	1.344
Narcotic use during pregnancy							.754	2.126
Herbal medicine use							-.327	.721
Intention to breastfeed							-.141	.868
Constant	-4.865		-3.597		-3.027		-3.282	
Adjusted R^2	.016		.030		.066		.078	

*p<0.05; **p<0.01; ***p<0.001

Table 5. Logistic Regression Assessing the Relative Effects of the Physical Environment, Socioeconomic Status, Clinical History of Medical Problems, and Behavioral Risk Factors on Mothers Having a Preterm Infant

	Model 1		Model 2		Model 3		Model 4	
	B	OR	b	OR	b	OR	b	OR
Sulfur dioxide	.791***	2.205	.957***	2.604	.743***	2.101	.712***	2.039

Ground-level ozone	.013	1.013	-.066	.936	-.062	.940	-.070	.932
Major road/highway within 200m	.097	1.102	.092	1.096	.085	1.089	.088	1.092
Distance between home and parks	.002	1.002	.003	1.003	-.008	.992	-.007	.993
Distance between home and variety	.013	1.013	.017	1.017	.001	1.011	.011	1.011
Maternal age			.008	1.008	-.006	.994	-.008	.992
% immigrants (2011)			-.043**	.958	-.034*	.966	-.036*	.965
% visible minorities			-.009	.991	-.009*	.991	-.009*	.991
% aboriginal			-.002	.998	.000	1.000	-.001	.999
% ≤ high school diploma			.004	1.004	.000	1.000	.001	1.001
% low income			.005	1.005	.003	1.003	.003	1.003
% lone-parent families			.001	1.001	-.001	.999	.000	1.000
Population density			.017	1.017	.006	1.006	.004	1.004
Underweight pre-pregnancy BMI			.381*	1.464	.435**	1.545	.416**	1.516
Previous preterm birth					1.518***	4.565	1.522***	4.583
Anxiety this pregnancy					.322*	1.380	.348*	1.417
Pre-pregnancy asthma					.292*	1.339	.311*	1.365
Pre-existing thyroid disease					.516**	1.676	.482**	1.620
Depression this pregnancy					.198	1.211	.215	1.240
Gestational diabetes					.634***	1.868	.561***	1.753

Pre-existing insulin dependent diabetes					.507	1.660	.508	1.663
Infant gender					.121	1.128	.113	1.119
Marijuana use during pregnancy							.423	1.527
Smoked during pregnancy							-.309*	.734
Alcohol use during pregnancy							-.220	.803
Opioid use during pregnancy							.345	1.412
Amphetamine use during pregnancy							.514	1.672
Constant	-3.123		-1.285		-1.148		-.796	
Adjusted R^2	.008		.018		.070		.073	

*p<0.05; **p<0.01; ***p<0.001

Highlights

- Out of 25,263 live births, 5.7% were low birth weight and 7.5% were preterm birth
- Maternal exposure to sulfur dioxide was a top predictor of adverse birth outcomes
- Previous preterm birth was also highly associated with both birth outcomes